Overview of the Recent Developments in Real-Time Optimisation via Modifier Adaptation

OVERVIEW OF THE RECENT DEVELOPMENTS IN REAL-TIME OPTIMISATION VIA MODIFIER ADAPTATION

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Keywords: Modifier Adaptation, Closed-loop Systems, Transient Measurements, Directional Modifier Adaptation, Model Mismatch

Modifier Adaptation (MA) is an explicit Real-Time (process) Optimisation (RTO) technique whereby measurements are incorporated in the optimisation framework to reject the detrimental effect of plant-model mismatch, parametric uncertainty and disturbances on the performances of chemical processes. One of the nicest features of modifier adaptation lies in its proven ability to reach the plant optimal inputs upon convergence even when the model at hand is structurally incorrect, a situation for which the classical two-step approach (update of the process model and re-optimisation with the updated model) fails.

The standard MA scheme is an iterative steady-state to steady-state constrained optimisation method that uses steady-state process measurements of the cost and of the constrained quantities and measurements or estimates of their gradients to construct affine-in-input correction terms, which are added to the modelled cost and constraints functions for the subsequent optimisation. The rationale behind is that, because of uncertainty, the model at hand is unable to predict the conditions of optimality of the plant, while the modifications brought by MA allows a reconciliation of the necessary conditions of optimality of the model and of the plant upon convergence.

Although very appealing, MA suffers from a certain number of limitations. The contribution of this article is to summarise recent developments in the field of RTO MA, mainly proposed by (but not limited to) the author and co-workers, which significantly increases its applicability to real-life problems and simplifies greatly its application to chemical processes. Despite these difficulties, MA has received a growing interest over the past few years and the number of successful applications has increased significantly [1].

The first discussed improvement concerns the difficulty of estimating the plant gradients when the number of inputs grows large. If finite differences is used (which is certainly not the best, but surely the easiest way of estimating gradients), the number of steady-state experiments that are required at each steady-state increases linearly with the number of degrees of freedom of the plant optimisation problem. It has been recently proposed to restrict the estimation of the plant gradients to certain privileged directions and methods for determining “optimally” these directions them have been proposed [2]. The approach in [2] has been successfully applied to the RTO of an experimental kite, without significant losses in optimality [3].

MA also heavily relies on the assumption that the degrees of freedom of the plant and of the model are the same. This is unfortunately only rarely the case as most plants are operated in closed-loop while models of complicated units are generally open-loop models. An extension of MA has been recently proposed to overcome this difficulty, which does not require any additional modelling [4].

As seen, RTO-MA is a steady-state to steady-state optimisation method, and therefore, multiple iterations may be required. A framework was proposed (and indeed discussed during the 14th SFGP congress in Lyon) to use transient measurements, and potentially converge in a single iteration to steady-state [5]. This approach was using static models and was thus hard to apply to processes exhibiting complex dynamics. An improvement of this framework had been recently proposed that combines transient measurements and dynamic models [6]. This improvement is shown to increase the applicability of MA with transient measurements to processes with, e.g., non-minimum phase behaviour if the dynamic model predicts it, which a static model can anyway not do.

Many other improvements have been also made, to replace the estimation of plant gradients by an outer optimisation loop [7] or by incorporating quadratic approximation to handle uncertainties [8], that will be briefly discussed if the duration of the oral presentation makes it possible. To conclude, it is important to notice that all these improvements, although requiring sometimes significant amendments to the standard MA problem formulation were all shown to preserve the capability of MA to reach the real optimal inputs of the plant, despite structural and parametric plant-model mismatch.

[1] A. Marchetti, G. François, T. Faulwasser and D. Bonvin. *Modifier Adaptation for Real-Time Optimization—Methods and Applications.* **Processes,** 4(55), 1-35, 2016.

[2] S. Costello, G. François and D. Bonvin. *A directional modifier-adaptation algorithm for real-time optimization*. **J. Process Control**, 39, 64–76, 2016.

[3] S. Costello, G. François and D. Bonvin. *Real-Time Optimizing Control of an Experimental Crosswind Power Kite*, **IEEE Trans. on Cont. Sys. Tech.**, in press, 2017.

[4] G. François, S. Costello, A. G. Marchetti and D. Bonvin. *Extension of Modifier Adaptation for Controlled Plants using Static Open-Loop Models*, in **Comp. and Chem. Eng.**, 93, 361-371, 2016.

[5] G. François and D. Bonvin. *Use of Transient Measurements for the Optimization of Steady-State Performance via Modifier Adaptation*, in **Ind. Eng. Chem. Res.**, vol. 53, num. 13, 5148-5159, 2014.

[6] T. De Avila Ferreira, G. François, A. G. Marchetti and D. Bonvin. *Use of Transient Measurements for Static Real-Time Optimization.* **Proceedings of the 20th IFAC World Congress***,* Toulouse, France, 2017, accepted.

[7] D. Navia, L. Briceño, G. Gutiérrez, and C. de Prada. *Modifier-adaptation methodology for real-time optimization reformulated as a nested optimization problem*. **Ind. Eng. Chem. Res., 54,** 12054–12071, 2015.

[8] W. Gao, S. Wenzel and S. Engell. *A reliable modifier-adaptation strategy for rea-time optimization.* **Comput. and Chem. Eng.** 91(4), 318-328, 2016.